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An energy-based approach to understand the effect of fretting displacement amplitude on grease-lubricated interface

L. Haviez [a,b,c], S. Fouvry [a,*], R. Toscano [b], G. Yantio [c]

[a] LTDS, UMR 5513, Ecole Centrale de Lyon, 36 Avenue Guy de Collongue, 69134 Ecully Cedex, France
[b] LTDS, UMR 5513, ENISE, 58 rue Jean Parot, 42023 Saint-Etienne Cedex2, France
[c] Sagem Défense Sécurité, 100 Avenue de Paris, 91300 Massy, France

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ABSTRACT

Grease lubricants are extensively used in contacts, usually to reduce friction and wear. Under small amplitude sliding, however, as in rolling systems subject to vibration, there is significant lubricant decay. The present study analyses the fretting sliding response of two grease lubricants subjected to small (i.e. partial slip) and large displacement amplitude (i.e. gross slip fretting). Tribological behavior and associated wear volume were investigated as a function of displacement amplitude. The investigation confirmed that, below a threshold displacement amplitude, scarce lubrication induced significant wear activation, while, above threshold, low friction and a low wear response were observed. A new effective friction energy wear concept is introduced to quantify wear rate whatever the fretting sliding condition.

1. Introduction

Nowadays, mechanical systems are expected to sustain extreme working conditions, due to increased power and optimized design. Although these mechanical systems are well known, new issues are emerging, especially when contact surfaces are subjected to vibration or cyclic stress. The main source of damage is fretting, which is small-amplitude oscillatory movement between contact surfaces. Fretting is encountered in all quasi-static loadings subjected to vibration, and thus concerns many industrial applications. Observed for the smallest displacement amplitudes, the partial slip is characterized by a closed elliptical fretting loop (i.e. tangential force evolution versus imposed displacement), associated with a composite contact displaying sliding and sticking zone (Fig. 1). The gross slip condition which is identified by a quadratic dissipative fretting loop is related to full sliding occurring over the entire surface. Waterhouse et al. [1] first indicated a correlation between the sliding condition and the damage evolutions. Considering a given normal loading and a stabilized sliding condition it has been shown that cracking is mainly encountered in partial slip condition, whereas wear is observed for larger amplitudes in gross slip condition.

A last aspect concerns the transition from gross slip fretting to reciprocating sliding. Different definitions have been introduced like the Varenberg sliding index [2] or the exposition ratio [3]. After this later approach, reciprocating is occurring when all the fretted surface is exposed to the ambient so that $\frac{\delta_g^*}{a} > 1$ with δ_g^* the sliding amplitude and a the contact radius. Into the present investigation, $e << 1$ so only partial and gross slip fretting condition will be considered.

There are many palliative solutions for reducing friction and preventing damage and wear while allowing relative movement between the contact surfaces [4,5]. Lubrication is one of the major methods for preventing fretting damage, achieving a remarkable reduction in the friction coefficient. Lubricants have been widely used in tribological systems such as rolling and sliding contacts, but their behaviors are not well understood because of the complexity of the chemical formulae, the various forms of lubricant (solid, liquid, semi-solid), temperature-dependent viscosity, etc. [6–13]. Other palliative solutions were proposed, such as topography modification (surface texturing) or thin film coatings [14]. The situation is even more complex for fretting sliding conditions where lubricant penetration in the interface is limited due to the very small sliding amplitude conditions. Many studies have estimated lubricant thickness as a function of the lubrication regime [15,16]. They demonstrated that lubricant thickness depends on entrainment speed for rolling-sliding contacts. Shen et al. studied the friction and wear responses of lubricant as a function of

* Corresponding author.
E-mail address: Siegfried.fouvry@ec-lyon.fr (S. Fouvry).

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normal force and displacement amplitude in a crossed-cylinder contact [17]. They showed that pressure affects oxygen access and induces a decrease in interface oxidation. However, residual oil from grease separation under friction may penetrate cracks and accelerate particle detachment [18]. McColl et al. also underlined that greased fretting interfaces depend on the pressure and penetration of the lubricant in the contact and the successive formation of a lubricant tribofilm layer [7,19]. They highlighted the effect of viscosity and fretting displacement amplitude: the lower the viscosity, the faster the lubrication process, whereas the larger

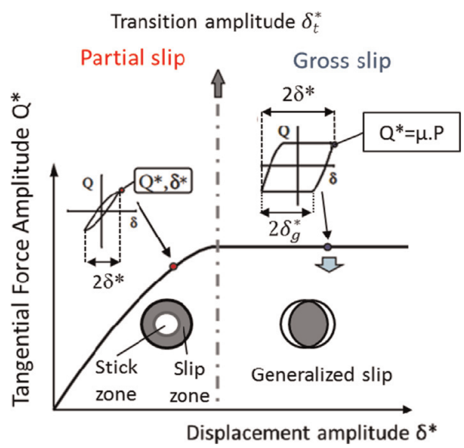

Fig. 1. Definition of partial and gross slip fretting domains.

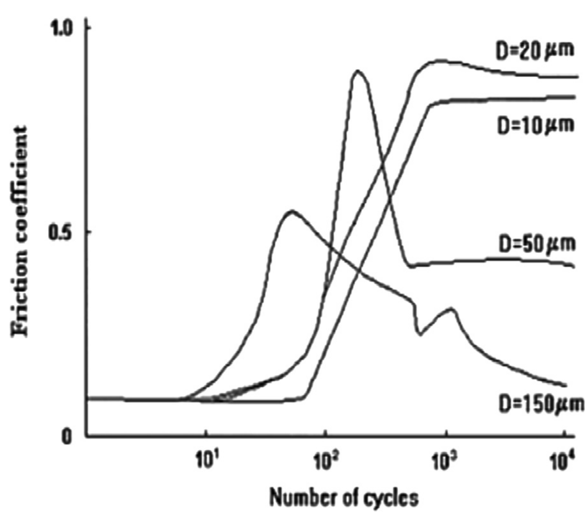

Fig. 2. Friction coefficient vs. number of cycles under grease lubrication. Normal load 300 N, frequency 1 Hz, ball diameter 23 mm –flat contact [9].

the fretting displacement amplitude the easier the tribofilm formation. This aspect was developed by Zhou et al. [14,15], showing that the friction coefficient in grease lubrication depends on the displacement amplitude coupled to a fretting regime description (Fig. 2); if the displacement amplitude is small enough to maintain a partial slip condition, the grease interface displays nearly dry contact behavior. Increasing the displacement amplitude under a gross slip condition and therefore inducing an effective fretting sliding, a non-monotonic evolution of the friction coefficient versus test duration is also observed. The larger the displacement amplitude (i.e. sliding amplitude), the smaller the maximum friction value and the faster the transition toward a low 0.2 tribofilm lubricated interface.

The purpose of the present study was to better quantify the effect of displacement amplitude on friction and above all on the wear response of a greased fretting interface. Considering the formation of lubricated tribofilm, an effective friction work concept is introduced to better quantify the wear rate of such interfaces whatever the sliding condition.

2. Experimental methods

2.1. Materials

The studied interface consisted of a 90° crossed-cylinder contact involving two chromium–molybdenum stainless steels: one case hardened with grinding steel (M1) and one solid tempered steel (M2). The M1 specimen had two surface layers: the first was the carburized phase, with hardness gradient between 760 HV and 550 HV (Fig. 3a); the second was the bulk, with 500 HV hardness. Both cylinders had radius R=7.5 mm. Therefore, according to Hertz, the configuration was equivalent to a sphere/plane configuration. Surface roughness was Ra=0.4 μm for both materials. Studied materials are usually used as bearing steel materials with high hardness, toughness and corrosion resistance. Grease was applied in excess in the contact area in order to maintain a constant quantity inside the fretted contact. All test procedures were performed with two commercial greases (G1 and G2) displaying respectively 50 and 10.3 cSt viscosity at 40 °C. G1 is used for wind turbines, usually for pitch and yaw bearing. It is synthetic base oil with lithium thickener. G2 is used for turbine engine aircraft, for lubricated highly load gears. It is made with synthetic diester base oil and a Microgel® non-melting inorganic thickener.

2.2. Fretting test

Fig. 3b shows the fretting wear test. An MTS hydraulic tension–compression machine regulated displacement between the crossed cylinders. All tests were performed at room temperature (22 °C ± 3 °C). All tests have been done a single time. Former

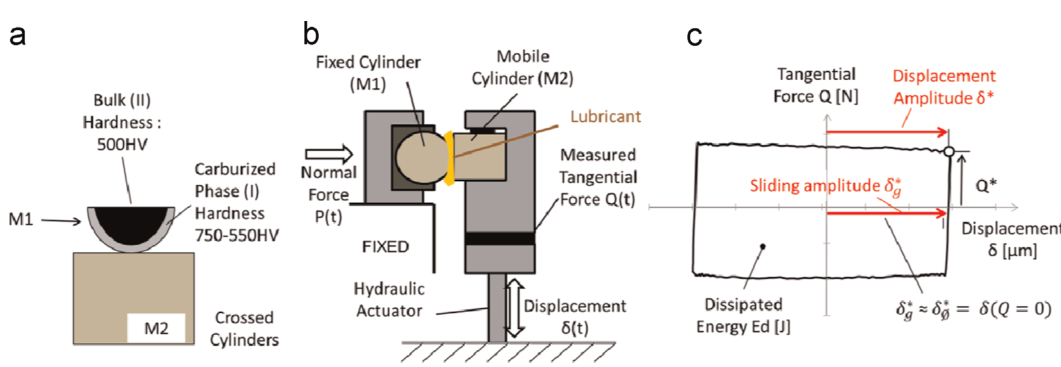

Fig. 3. a) Contact configuration (crossed cylinders); b) Fretting set-up; c) Fretting cycle analysis.